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The Impact of Appertisation and Boiling on the Nutritional Content of Okra (Abelmoschus esculentus Cultivar Hiré) Cultivated in Côte D'Ivoire

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Abstract Food and nutritional insecurity linked to the seasonal availability of nutrient-dense vegetables remains a major challenge in Côte d'Ivoire, where okra (Abelmoschus esculentus, cultivar Hiré) is a staple ingredient of traditional sauces but is highly perishable and available only during a short harvest window. Boiling, the most common household preparation method, is known to cause substantial losses of heat- and water-soluble nutrients, while industrial canning (appertisation) has rarely been evaluated under local conditions as an alternative that can extend availability while preserving nutritional quality. The aim of this study was to evaluate the effects of appertisation and boiling on the nutritional composition of okra. It was prepared using these two heat treatment methods and then analyzed to determine its macronutrient, mineral, vitamin C, and bioactive compound content. The results revealed that fresh okra had the highest levels of protein (14.11%), polyphenols (5.84 mg EAG/g), flavonoids (17.75 mg EQ/g), and vitamin C (31.13 mg/100 g). Appertised okra retained its protein (13.84%), essential minerals (calcium: 82.16 mg/100 g DM, phosphorus: 64.03 mg/100 g DM), and vitamin C (26.55 mg/100 g) well. Conversely, water-cooked okra is high in fiber (20.72%), but experiences considerable nutritional decline, especially in vitamin C (10.26 mg/100 g). Thanks to its preserved nutritional qualities and shelf life, canned okra represents a promising alternative for sustainably promoting local production and playing a key role in the food and nutritional security of the population in Côte d'Ivoire.

Keywords: *Okra, canning, boiling, nutritional composition*

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1. Introduction

In Côte d'Ivoire, as in much of West Africa, vegetable production remains strongly concentrated in a short rainy-season window; once this period ends, supply falls sharply, prices rise, and a substantial share of the harvest is lost between the field and the plate because affordable preservation options remain limited [1,2]. This seasonality directly constrains food and nutrition security because several affected vegetables, including okra, are important dietary sources of protein, minerals, and vitamin C for local populations [3]. Extending okra's availability beyond the harvest season without eroding its nutritional value is therefore a practical priority.

Okra (*Abelmoschus esculentus L.*) is a vegetable plant of the Malvaceae family, whose edible fruits are an essential food in tropical and subtropical countries [4]. In 2023, global production exceeded 11.5 million tonnes, with more than 3 million tonnes coming from Africa [5].

An extremely versatile plant, okra is notable for the potential use of all its parts, namely the roots, stems, leaves, fruits, and seeds, for food, medicinal, craft, or industrial purposes. This crop is of considerable socio-economic and nutritional importance in several countries where it is considered a staple food [6].

In Côte d'Ivoire, okra production is no longer limited to the season; it also extends into the off-season in urban areas, where it is often combined with other vegetables [7]. It was estimated at 101,154.91 tonnes in 2023 [5]. The most common varieties locally are Hiré, Kirikou, Emerald, Fatou, Tomi, Adjouablé, and Koto [7].

It occupies a prominent place in the country's gastronomic heritage, forming part of traditional sauces generally served with dishes based on cereals, roots, or tubers, such as the "Djoumgblé" and "Kôpè" sauces [8].

Nutritionally, okra is one of the most remarkable vegetables. Composition studies report high levels of protein, essential minerals such as calcium, phosphorus, and potassium, dietary fiber, B vitamins, and antioxidant phytochemicals in the pods [9], whilst the seeds contain around 20% protein and 20% fat [10]. Consuming immature pods can provide up to 4,550 kcal/kg of energy [11]. Taken together, these characteristics make okra an important vegetable for diet, food security, and nutritional security in tropical regions [1].

However, okra is rarely eaten raw. Cooking is essential for improving taste, texture, and consumer acceptability [12]. This thermal processing offers both benefits and drawbacks. It effectively inactivates antinutrients and destroys potentially harmful microorganisms [13], but if the cooking method is not carefully chosen, it can reduce the vegetable's nutritional value [14]. Boiling often causes a loss of vitamin C and a decrease in the antioxidant capacity of vegetables [15], because heat and prolonged exposure to water promote the leaching of water-soluble vitamins and phenolic compounds into the cooking liquid [16].

Each cooking method affects the nutrients in okra differently. Whether you choose to boil, steam, roast, microwave, or fry it, the nutritional changes vary considerably [17]. Cooking can even increase the concentration of certain beneficial compounds while reducing others [18,19]; some studies report that blanching or frying can raise the antioxidant content of vegetables [20], whereas others report the opposite for simple blanching [21,22]. These apparently contradictory findings likely reflect cellular-level transformations: heat disrupts plant cell structures, releasing some nutrients while degrading others [23,24].

In addition to these domestic methods, industrial canning (appertisation) is a promising option. This technique sterilizes okra in airtight jars, which not only allows it to be stored for a long time but also preserves its nutritional composition satisfactorily [25]. This concern is particularly relevant for populations that rely heavily on these vegetables as their main source of micronutrients essential for health [26,27].

Despite this evidence, no study had directly compared boiling and canning for the Hiré variety of okra grown in Côte d'Ivoire, even though this variety dominates local urban markets [7]. Most previous comparative studies on cooking methods and nutrient retention have focused either on leafy vegetables or on okra grown outside West Africa. It therefore remained to be determined whether the same trends would apply to a fruit vegetable of major economic and dietary importance at the local level. This study fills this gap by providing, to the best of our knowledge, the first direct nutritional comparison of fresh, boiled, and tinned Hiré okra, combining analyses of composition, minerals, vitamin C, and bioactive compounds within a single experimental protocol. More specifically, the objectives of this study were: (i) to assess the impact of canning and boiling on the nutritional composition of okra, and (ii) to identify, based on these results, which processing method offers the best balance between nutrient retention and extending the shelf life of okra grown in Côte d'Ivoire.

2. Materials and Methods

2.1. Plant Material

The plant material used in this study consisted of a variety of okra, *Abelmoschus esculentus*; cultivar Hiré. The okra was harvested at physiological maturity from a market garden in Grand Yapo, Agboville region. Once harvested, the samples were immediately placed in an ice-filled cooler and then transported to the Laboratory of Food Biochemistry and Tropical Product Processing (LBATPT) at Nangui ABROGOUA University for the required analyses.

2.2. Methods

2.2.1. Processing

2.2.1.1. Cooking Okra in Water

The okra fruits were cooked using a slightly modified version of the method described in [28]. Five hundred grams of fresh, pre-washed fruit were immersed in 1.5 liters of tap water and boiled for 50 minutes. The fruits were cooked at this temperature until they became soft, and the seeds' color changed from white to purple. After cooking, the okra was drained, cooled to room temperature, and then placed in an oven at 45°C for 24 hours. Finally, the dried okra was ground to obtain okra powder.

2.2.1.2. Canning Okra (Appertisation)

Canning was carried out using a method adapted from the protocol described in [29]. The okra was washed, sorted, graded, and then blanched in boiling water at 100°C for 2 minutes. The glass jars and their lids were sterilized at 100°C for 20 minutes beforehand. The blanched okra was placed in the sterilized jars to a depth of 2.5 cm from the rim, then covered with hot blanching water, leaving a 2.5 cm headspace. After removing air bubbles and vacuum sealing the lids, the jars were sterilized in an autoclave at 116 °C for 25 minutes. The preserves were then cooled to room temperature and stored in the dark for subsequent analysis.

2.2.2. Analysis Method

2.2.2.1. pH Determination

The pH was determined according to the standard method described in [30]. Ten grams of okra were ground in 100 ml of distilled water, macerated for 30 minutes, and then centrifuged at 3,500 rpm for 30 minutes. Ten grams of okra were ground in 100 ml of distilled water, macerated for 30 minutes, and then centrifuged at 3,500 rpm for 30 minutes. The pH of the supernatant was measured using a PHS-550 pH meter.

2.2.2.2. Determination of Dry Matter and Moisture Content

The dry matter and moisture contents were determined according to the standard method described in [31]. Five grams of the sample were dried in an oven at 100 ± 5°C for 24 ± 0.5 hours, until a constant mass was reached. The results were expressed as a percentage.

2.2.2.3. Determination of Protein Content

Protein was measured using the Kjeldahl method [31]. One gram of dried and ground sample was mineralized at 400 °C for 150 minutes with a catalyst (selenium + K_2SO_4) and 20 mL of H_2SO_4 (95-97%). The ammonia released after distillation was trapped in a mixture of boric acid (4%) and mixed indicator, then titrated with 0.1 N H_2SO_4. The results were expressed as a percentage of dry matter using a conversion factor of 6.25.

2.2.2.4. Determination of Lipid Content

Lipids were extracted using the Soxhlet method [31]. Five grams of the sample were extracted with 300 mL of hexane for 7 hours. After evaporation of the solvent in a rotary evaporator and drying at 100°C for 20 minutes, the results were expressed as a percentage of dry matter.

2.2.2.5. Determination of Ash Content

The ash content was determined according to the standard method described in [31]. Five grams of the sample were incinerated in a muffle furnace at 550 °C for 12 hours. The results were expressed as a percentage of dry matter.

2.2.2.6. Determination of Total Fiber Content

Total fiber content was determined according to the standard method described in [31]. 2 g of the sample was treated sequentially with 50 mL of 0.25 N H_2SO_4 and 50 mL of 0.31 N NaOH, each under reflux for 30 minutes. The filtered residue was dried at 105°C for 8 hours, then incinerated at 550°C for 3 hours. The results were expressed as a percentage of dry matter.

2.2.2.7. Determination of Carbohydrate Content

Carbohydrate content was calculated by difference according to the method described in [32] and expressed as a percentage of dry matter.

2.2.2.8. Determination of Energy Value

The energy value was calculated by multiplying the carbohydrate, fat, and protein contents by the respective Atwater factors of 4, 9, and 4 [33]. The results were expressed in kilocalories (kcal).

2.2.2.9. Determination of Mineral Content

Mineral content was determined by atomic absorption spectrophotometry according to the standard method described in [31]. Ashes (0.5 g) were dissolved in 31 mL of a mixture of acids ($HClO_4$, HNO_3, H_2SO_4; 1:1, v/v), heated until white fumes appeared, diluted with 50 mL of distilled water, and then boiled for 30 minutes. After filtration, the contents were determined using a flame atomic absorption spectrophotometer (Varian AA.20) by comparison with standard solutions.

2.2.2.10. Determination of Vitamin C Content

Vitamin C was measured by titration with 2,6-dichlorophenol-indophenol [34]. 5 g of the sample was mixed with 5 mL of HPO_4-CH_3COOH solution and 10 mL of distilled water, then titrated with a DCPIP solution (8.61×10^{-3} mol/L) until a persistent pink color was observed for 30 seconds. The results were expressed in mg/100 g of dry matter.

2.2.3. Analysis of Secondary Metabolites

2.2.3.1. Preparation of Ethanol Extracts

The samples, dried at 45°C for 24 hours, were ground. Five grams of ground material were incubated at 25°C for 24 hours in 50mL of 80% ethanol with mechanical agitation. After centrifugation at 4,000 rpm for 5 minutes, the supernatants were recovered, and the pellets were re-extracted twice. The extracts were concentrated at 35°C to 50 mL using a rotary evaporator and then stored at 20°C.

2.2.3.2. Determination of Total Polyphenols

Total polyphenols were determined using the Folin–Ciocalteu method described in [35]. The absorbance was read at 725 nm after 30 minutes of incubation in the dark. The results were expressed in mg gallic acid equivalent (GFE)/100 g dry matter.

2.2.3.3. Determination of Total Flavonoids

Flavonoid content was determined according to the method described in [36] with aluminum chloride. The absorbance was read at 415 nm after 30 minutes of incubation. The results were expressed in mg quercetin equivalent (EQ) per 100 g of dry matter.

2.2.3.4. Determination of Gallic Tannins

Gallic tannins were determined according to the method described in [37] using vanillin as the reagent. The absorbance was read at 500 nm after 20 minutes of incubation in the dark. The results were expressed as mg of tannic acid equivalents (EAT)/100 g dry matter.

2.2.4. Statistical Analysis of Results

The values obtained are expressed as arithmetic means accompanied by the standard deviation. The data collected were analyzed using Statistica software (version 7.1). The means were compared using one-way analysis of variance (ANOVA), followed by Duncan's post hoc test at the 5% significance level to identify significant differences between samples.

3. Results

3.1. Effect of Heat Treatment on the Nutritional Composition of Okra

The nutritional composition of fresh okra (FO), boiled okra (BO), and canned okra (CO) is shown in Table 1. The dry matter, protein, and carbohydrate content of fresh okra is significantly higher (P < 0.05), followed by that of canned okra and boiled okra. Canned okra has the highest lipid content (1.90 ± 0.01%), while fresh okra and boiled okra have similar but significantly lower contents. Okra cooked in water stands out for having a significantly higher total fiber content (20.72 ± 0.16%) than canned or fresh okra. In terms of ash content, canned okra and fresh okra had similar levels (9.15 ± 0.01% and 9.08 ± 0.17%, respectively), which were significantly higher than those of boiled okra. In terms of energy value, fresh okra is the richest with 321.75 ± 0.56 kcal/100 g DM (P < 0.05), followed by canned okra and okra cooked in water. Regarding pH, a significant difference was observed between fresh okra (6.73 ± 0.01) and heat-treated samples.

Table 1. Nutritional characteristics of different okra samples

Biochemical parameters (%DM)	Okra samples		
	FO	BO	CO
pH	6.73 ± 0.01^b	5.98 ± 0.10^a	5.95 ± 0.01^a
Dry matter	90.65 ± 0.09^c	83.59 ± 0.16^a	88.78 ± 0.09^b
Moisture	9.35 ± 0.07^a	16.41 ± 0.13^c	11.22 ± 0.08^b
Protein	14.11 ± 0.06^c	10.87 ± 0.04^a	13.84 ± 0.01^b
Total lipids	1.35 ± 0.01^a	1.29 ± 0.03^b	1.90 ± 0.01^c
Ash	9.08 ± 0.17^b	7.62 ± 0.01^a	9.15 ± 0.01^b
Total fibre	12.16 ± 0.10^a	20.72 ± 0.16^c	15.44 ± 0.13^b
Carbohydrates	63.28 ± 0.13^c	59.50 ± 0.15^a	59.69 ± 0.20^b
Energy value (kcal/100g DM)	321.75 ± 0.56^c	293.09 ± 0.65^a	311.19 ± 0.71^b

Values (mean ± standard deviation, n = 3) in the same row with different letters are significantly different at the 5% level according to Duncan's post hoc test. FO: Fresh okra; BO: Boiled okra; CO: Canned okra.

3.2. Effect of Heat Treatment on Mineral Content

Table 2 shows the mineral content of fresh okra (FO), boiled okra (BO), and canned okra (CO). The results revealed a significant variation, at the 5% threshold, between the samples for most of the minerals analyzed. Microminerals, particularly potassium, calcium, phosphorus, and magnesium, were the most abundant elements. Potassium is the most abundant mineral, with high concentrations in fresh and canned okra of 301.16 ± 0.04 mg/100 g DM and 306.55 ± 0.04 mg/100 g DM, respectively. In contrast, okra cooked in water showed a significant decrease with a lower concentration of 99.34 ± 0.03 mg/100 g DM. A similar trend was observed for calcium, phosphorus, and magnesium. Regarding trace minerals, there was no significant difference in sodium content between fresh and canned okra, with concentrations of 9.14 ± 0.00 mg/100 g DM, whereas okra cooked in water had a significantly lower content of 2.10 ± 0.00 mg/100 g DM. Iron, manganese, and copper showed the same trend: higher concentrations in canned and fresh okra, and lower in okra cooked in water. As for zinc, its levels were similar in fresh and boiled okra (0.63 ± 0.02 mg/100 g DM and 0.61 ± 0.02 mg/100 g DM, respectively), whereas canned okra showed a significant increase, at 0.76 ± 0.02 mg/100 g DM.

Table 2. Mineral content of different okra samples

Type of minerals (mg/100 g DM)	Okra Samples		
	FO	BO	CO
Calcium	82.13 ± 0.05^b	71.05 ± 0.04^a	82.16 ± 0.05^b
Phosphorus	63.25 ± 0.04^b	29.27 ± 0.05^a	64.03 ± 0.02^c
Magnesium	57.27 ± 0.02^b	30.94 ± 0.04^a	57.46 ± 0.03^c
Potassium	301.16 ± 0.04^b	199.34 ± 0.03^a	306.55 ± 0.04^c
Sodium	9.14 ± 0.00^b	2.10 ± 0.00^a	9.14 ± 0.00^c
Manganese	0.51 ± 0.03^b	0.10 ± 0.02^a	0.60 ± 0.04^c
Iron	0.73 ± 0.02^b	0.57 ± 0.03^a	0.86 ± 0.04^c
Copper	0.05 ± 0.01^b	0.01 ± 0.00^a	0.07 ± 0.01^c
Zinc	0.63 ± 0.02^a	0.61 ± 0.02^a	0.76 ± 0.02^b

Values (mean ± standard deviation, n = 3) in the same row with different letters are significantly different at the 5% level according to Duncan's post hoc test. FO: Fresh okra; BO: Boiled okra; CO: Canned okra.

3.3. Effect of Heat Treatments on the Bioactive Compounds in Okra

The phenolic compound composition of fresh okra (FO), boiled okra (BO), and canned okra (CO) is shown in Table 3. The results revealed that fresh okra had significantly higher (P < 0.05) levels of total polyphenols (5.15 ± 0.01 mg EAG/g), flavonoids (9.70 ± 0.27 mg EQ/g), and tannins (23.81 ± 0.30 mg EAT/g) than those found in boiled and canned okra. For the latter two, the measured values showed no significant difference (P > 0.05) for total polyphenols, flavonoids, or tannins. For ascorbic acid, a significant difference (P < 0.05) was observed among the three samples. Fresh okra had the highest content (29.30 ± 0.04 mg/100 g), followed by canned okra (26.55 ± 0.03 mg/100 g), while boiled okra had the lowest content (10.26 ± 0.04 mg/100 g).

Table 3. Bioactive compound content of different okra samples

Bioactive compounds	Samples		
	FO	BO	CO
Total polyphenols (mgEAG/g)	5.84 ± 0.02^b	3.91 ± 0.07^a	3.93 ± 0.02^a
Flavonoids (mgEQ/g)	17.75 ± 0.12^b	7.05 ± 0.23^a	7.17 ± 0.14^a
Gallic tannins (mgEAT/g)	26.91 ± 0.21^b	21.40 ± 0.22^a	21.40 ± 0.34^a
Vitamin C (mg/100g)	31.13 ± 0.02^c	10.26 ± 0.04^a	26.55 ± 0.03^b

Values (mean ± standard deviation, n = 3) in the same row with different letters are significantly different at the 5% level according to Duncan's post hoc test. FO: Fresh okra; BO: Boiled okra; CO: Canned okra.

4. Discussion

The cooking method can influence the micronutrient levels in vegetables. Biochemical analysis revealed that water-cooked okra contained more water compared to fresh or canned okra. This difference may result from greater changes in the cell wall during cooking in water than during canning. These modifications enhance water penetration into cells, boosting water flow into the intracellular space. This phenomenon is governed by osmosis, whereby water moves from a less concentrated to a more concentrated area [38,39]. This increases contact between the inside of the okra and the cooking water, resulting in higher moisture content in freshly cooked okra than in canned okra.

During boiling and canning, okra's fiber content changed notably compared to fresh okra. The significant increase during boiling is probably due to fiber hydration and mucilage swelling, which facilitate the extraction of soluble fiber. Canning also increased fiber content, but less so than boiling. This finding is consistent with previous reports [40], which demonstrated that cooking alters the soluble and insoluble fiber content by transforming the physical and chemical properties of the cell walls. From a nutritional perspective, dietary fiber is essential for regulating intestinal transit and preventing chronic diseases such as diabetes, cardiovascular disease, and obesity [41,42].

Ash content can be used to estimate the total mineral content of okra samples [43]. In this study, fresh and canned okra had similar ash contents, which were significantly higher than those of boiled okra. This difference could explain the higher mineral concentrations observed in these samples. Comparable results have been reported previously, with ash contents of 7.46% for Sesamum radiatum and 9.78% for Justicia galeopsis, two edible plant species that were cooked for 20 minutes.

Microelement analysis supports this trend. Calcium, phosphorus, magnesium, and potassium are found in much higher amounts in fresh and canned okra compared to okra cooked in water. The reduction in minerals during water cooking is likely due to their solubilization and diffusion into the cooking liquid. These findings are consistent with previous observations [45]. The leaching effect is especially pronounced for phosphorus and magnesium, with levels dropping by more than 50%. Conversely, appertisation, which reduces prolonged water contact, better maintains mineral levels, nearly matching those in fresh okra. These findings emphasize the nutritional value of canned okra, which is a rich source of essential minerals. These minerals are crucial because they support the function of hormones and enzymes in the body [46]. A well-preserved mineral composition could help compensate for certain nutritional deficiencies [47].

The protein content is lowest in boiled okra, whereas fresh and tinned okra contain much higher levels. This difference can be explained by the fact that boiling causes certain proteins to dissolve and diffuse into the cooking liquid, as shown by previous research. [48]. On the other hand, heat treatment by appertisation limits this type of loss, allowing for better protein preservation. The canned okra's protein content exceeds 12%, the threshold for labeling a food as protein-rich. [49]. These results suggest that processed okra could be a complementary protein source in diets, particularly in tropical regions. It could also help combat protein-energy malnutrition in vulnerable populations [50,49].

Regarding lipids, the results showed an increase in content. This finding is consistent with the literature, which has described okra as a low-lipid vegetable. The results are similar to those reported previously [51]. For fresh *Moringa oleifera* leaves with a fat content of 1.31%. Since fat is insoluble in water, it does not generally lose mass during cooking. However, the increase in lipids in the canned samples could be due to heat- and water-induced degradation of pectin, thereby facilitating their release [39].

Carbohydrate levels are high in all samples, with fresh okra having the highest, followed by canned and boiled varieties. These numbers reflect okra's energy potential and account for the differences in energy observed among the samples. The cooking method, including water boiling and appertisation, affected the energy content of the okra, likely due to changes in protein, fiber, and carbohydrate levels. Overall, fresh okra has the highest energy value, with canned and boiled okra trailing.

Analysis of bioactive compounds revealed that fresh okra had significantly higher levels of polyphenols, flavonoids, and tannins compared to heat-treated samples. The study showed that the polyphenol, flavonoid, and tannin contents are roughly equal in boiled and canned okra, suggesting that thermal processing induces similar degradation of these compounds. Total polyphenols decreased to approximately 3.9 mg EAG/g after heat treatment; flavonoid content decreased to approximately 7.1 mg EQ/g; and gallic tannins reached approximately 21.40 mg EAT/g for both treatments. These results are comparable to those obtained by previous researchers. [52], who measured total polyphenol content of 2.36 mg EAG/g, flavonoid content of 10.29 mg EQ/g DM, and condensed tannin content of 33.29 mg EAT/g in non-heat-treated okra fruits grown in Benin. Despite the decrease observed after treatment, the values obtained remain high, particularly for tannins. The latter are known for their beneficial biological properties. They play a role in fighting infections, promoting healing, regulating excessive intestinal secretions, toning soft tissues, and repairing skin lesions [53].

Furthermore, the vitamin C content in okra varies significantly with processing. Fresh okra contains the most, followed by canned okra, while boiled okra has the least. This variation is likely due to vitamin C's water-soluble and heat-sensitive properties, which cause it to degrade during extended cooking or in aqueous environments. Previous studies have shown that high temperatures combined with prolonged cooking times lead to significant degradation of vitamin C [54]. The losses observed in okra cooked in water are consistent with previous reports [55]., who also reported a decrease in vitamin C in the leaves *of Hibiscus sabdariffa* and of *Corchorus olitorius* after cooking. However, canning appears to preserve vitamin C better than boiling, likely because airtight packaging limits prolonged exposure to heat and oxygen.

5. Conclusion

In line with the objectives of this study, the results show that appertisation markedly better preserves the protein, mineral, and vitamin C content of okra (cultivar Hiré) than boiling, which causes considerable nutrient losses through leaching into the cooking water. Although both heat treatments reduce polyphenol, flavonoid, and tannin levels compared with fresh okra, canned and boiled samples retain concentrations that remain nutritionally and biologically relevant. Overall, appertisation emerges as the processing method best able to reconcile extended shelf life with nutritional quality, confirming its potential as a viable strategy for improving the availability of okra beyond its harvest season. Canned okra, combining a favorable nutrient profile with long-term storability, could thus make a tangible contribution to food and nutritional security in Côte d'Ivoire, particularly where access to fresh vegetables is seasonal or limited. Further work should assess the microbiological safety and sensory acceptability of appertised okra and evaluate its cost-effectiveness for small-scale processors to support wider adoption of this technique.

Contributions of the Authors

Aïssatou Coulibaly: Conceptualization, data curation, methodology, resources, visualization, first draft, revision, and correction

Adam Camille Kouamé: Conceptualization, writing, revision, and correction

Victor Christ Emmanuel Atta: Conceptualization, investigation, writing of the first draft, revision, and correction

Hemayoro Sama: writing, revision, and correction

N'Guessan Georges Amani: Revision and correction

Conflict of Interest

The authors declare no conflicts of interest.

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